

The Impact of Pressure Regulation of Cryogenic Fluids and EPICS EPID Feedback on the Monochromatic Beam Position Stability of the 7ID Beamline at the Advanced Photon Source.

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Abstract.

The first crystal mount of the double-crystal Si (111) cryogenically cooled monochromator of the 7ID beamline at the Advanced Photon Source (APS) is slightly sensitive to pressure variations in the cryogenic lines. Pressure variations during a liquid nitrogen cryocooler fill every 4 hours move the beam by tens of microns. Pressure variations due to the cryocooler closed-loop pressure control with a heater element (around 0.3 psi) move the beam by 5 microns every 15 seconds. We have recently stabilized the coolant pressure with a simple pressure regulator that is in use at many beamlines of the APS. This paper shows the improvements in beam position stability made using this simple yet effective pressure-regulation circuit. We also recently added beam-position feedback to the second-crystal Bragg angle of the monochromator. The Experimental Physics and Industrial Control System (EPICS) Enhanced Proportional-Integral-Differential (EPID) feedback record implementation resulted in an additional improvement of the standard deviation of the beam position to 0.5 μm .

Keywords: beam stability, PID feedback, cryogenic fluids.

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INTRODUCTION

In the past few years, we have reported several improvements in the beam stability delivered by the beamline 7ID cryogenic monochromator [1, 2]. The monochromator is a double-crystal cryogenically cooled Si (111) monochromator developed at the APS and in use at several of its beamlines [3]. In 2001, we improved the mechanical stability of the first crystal mount [1] to reduce its sensitivity to pressure variations in the cryogenic lines. With the recent installation of a fluorescence-based X-ray beam position monitor, we have been able to use the beam position to test several upgrades of the monochromator [2]. In this paper we report on recent improvements in the pressure stabilization of the liquid nitrogen coolant of the monochromator first crystal. We discuss also the improved performance resulting from using EPICS EPID feedback [4] on the vertical beam position.

EXPERIMENTAL METHOD

The standard Oxford cryocooler controls the pressure in its liquid nitrogen closed loop by boiling off some liquid with a heater stick controlled by a Proportional-Integral-Differential (PID) electronic controller (see Figure 1b). On 7ID, it was difficult to keep this pressure stable to better than 0.3 psi (1 psi \approx 6.9 kPa) in normal operation. Since the summer of 2004, the 7ID Oxford cryocooler system closed loop is controlled by an Omega PRG101-25 pressure regulator with a range of 2 to 25 psi, supplied by boil off dry nitrogen gas from a liquid nitrogen tank. In the initial test of this system (see Fig. 3a), a 0-60 psi regulator was used instead (Omega PRG101-60). To monitor the stabilized closed-loop pressure, we connected to the closed loop a high-resolution pressure sensor Omega PX271A-030GI. It has a range of 0 to 30 psi, outputting a current in this range from 4 to 20 mA. The current is dropped into a 500 Ω resistor, and the voltage difference is digitized with an EPICS-controlled IP-330 16-bit A/D module.

In the past, the cryopump was found to work best when the low-pressure vessel surrounding the closed loop can vent out its boil-off nitrogen gas directly to the experimental hall without long exhaust lines. When the cryopump is inside a hutch, the dry nitrogen generated during the pump's operation must be vented outside the hutch for safety reasons

to prevent any oxygen deficiency from building up. In the fall of 2005, we moved the cryocooler outside of the 7ID-A hutch. A platform was built to mount the cryocooler system on the roof of 7ID-A, and new vacuum-jacketed hoses were purchased. The platform was built using a Unistrut frame and a light Al floor. The long exhaust line is no longer needed. There is now more room inside the 7ID-A hutch, and the cryocooler can be accessed for servicing while the beam is on. We have found that the noise level during the fill has been significantly reduced.

Since November 2004, we can stabilize the monochromator second-crystal angle with a closed-loop EPICS EPID record developed at the APS. The feedback is done on the vertical beam position by adjusting the monochromator second crystal. The beam position is measured by a fluorescence x-ray beam-position monitor (BPM) placed 49 m from the source and 19 m from the monochromator [5, 2]. The second Si (111) crystal fine angle is controlled by a Queensgate Instruments Ltd MT-15UVAC electrostrictive transducer controlled by a MC10-160 controller from the same company. The transducer has a range of $16\text{ }\mu\text{m}$ and is mounted on one end of a kinematic mount with a lever arm of about 10 cm. An EPICS-controlled digital 12 bit D/A board (Xycom 540) with 0 to 10 V output is fed to the control input of the MC10 controller, allowing the PID loop to control the second-crystal Bragg angle with a range of about $160\text{ }\mu\text{rad}$. The PID loop corrects the angular fluctuations of the first crystal due to pressure variations. It was mainly installed to improve the position stability while scanning the monochromator energy.

RESULTS

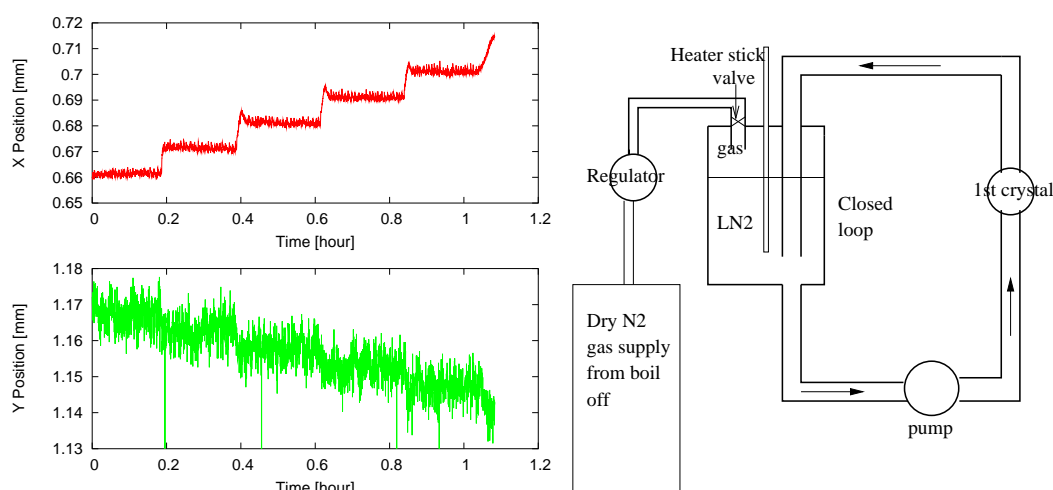


FIGURE 1. A)(Left) X-ray beam position (X,Y) versus time, following 4 pressure increases of 1 psi in the closed loop. B) (right) New closed-loop regulated pressure system.

Figure 1a shows the impact of the closed loop pressure on the beam position stability. For each step of 1 psi, the beam moves by 10 and $5\text{ }\mu\text{m}$ in the horizontal and vertical directions respectively. This result is fairly consistent with measurements of the first-crystal tilt angle versus applied pressure made with a tiltsensor [1]. It was found then that, by pressurizing the cooling lines with dry nitrogen at room temperature, the Bragg angle moved by $0.2\text{ }\mu\text{rad/psi}$, thus 20 m from the monochromator, one expects a motion of $2 * 20\text{ m} * 0.2\text{ }\mu\text{rad/psi} = 8\text{ }\mu\text{m/psi}$.

Figure 2a shows the measured regulated pressure and outside Dewar level (it cools the closed loop) versus time. Figure 2a shows that the Dewar level refills every 2.5 hours, resulting in a brief pressure variation of the closed-loop pressure off less than one psi. Without the regulator in use, these pressure spikes tend to be on the order of 5 psi, significantly larger (not shown). Figure 2b displays the short-term pressure stability. The average pressure is 18.759 psi, and the standard deviation is 0.002 psi, resulting in about 0.01 % pressure stability away from the Dewar fill.

Figure 3a shows the horizontal X-ray beam position versus time with the cryopump heater circuit on and when one uses the new pressure-regulated circuit. The short-time rms beam position fluctuations are reduced by nearly a factor of three ($1.9/0.7$) when the pressure is stabilized by the simple 0-60 psi pressure regulator. This is a significant improvement over the heater circuit, which has since not been used at the beamline.

Figure 4a shows the cryogenic Dewar levels of the cryopump. The outer Dewar level fills periodically between 60 and 65 %. The drop of the closed-loop level (bottom panel) in the first 15 hours is due to a leak in the closed loop. After

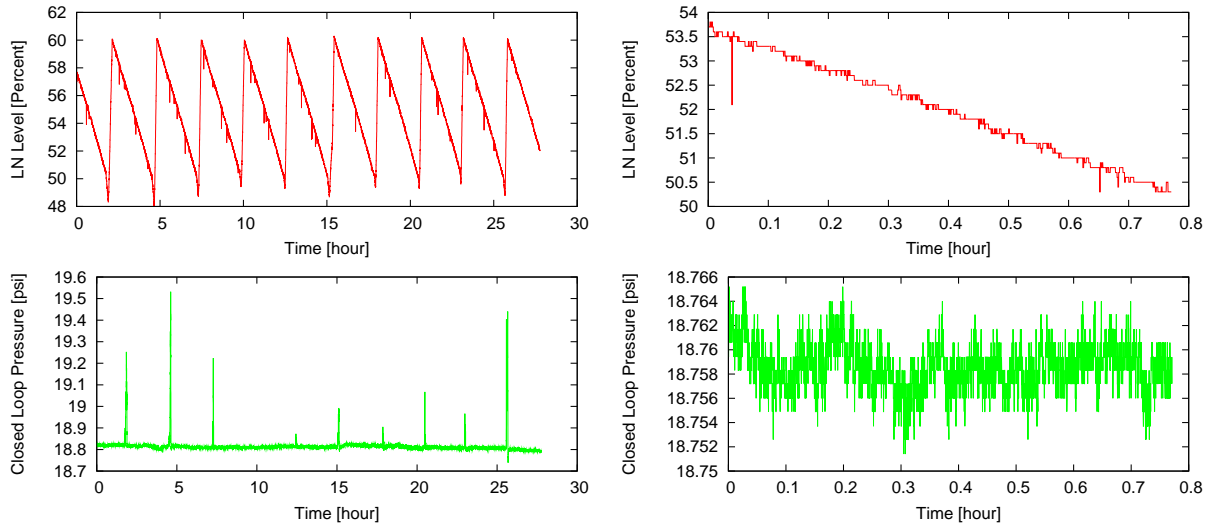


FIGURE 2. A) (left) Outer Dewar level (top) and measured pressure in the closed loop (bottom) versus time with the new regulated pressure system. B) (right) Short 0.8-hour-long time series of the same quantities.

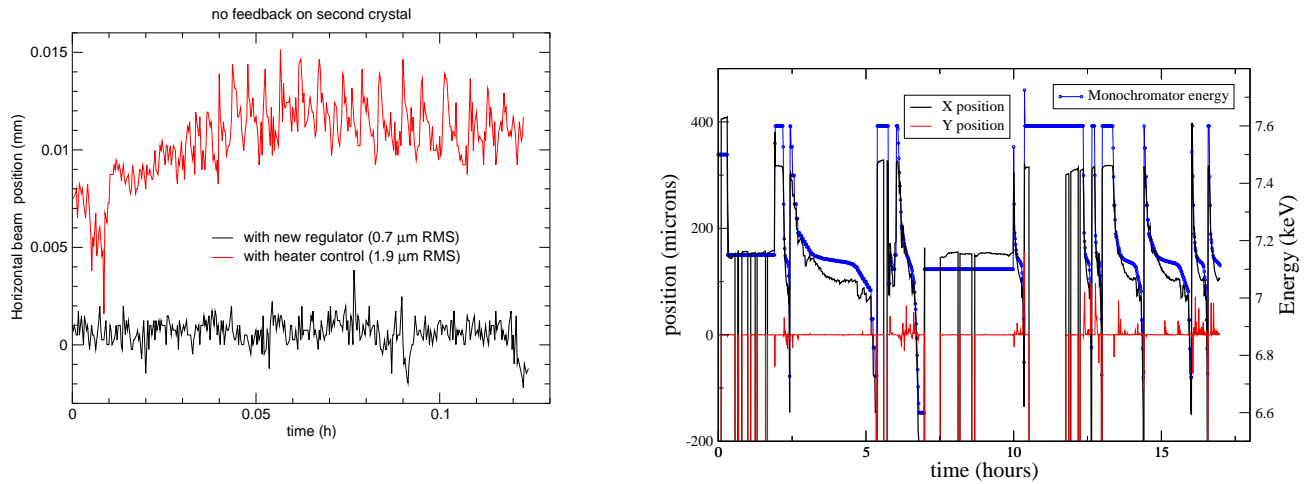


FIGURE 3. A) (left) Horizontal X-ray beam position versus time. The data were taken at a frequency of about one Hz. B) (right) Beam positions and monochromator energy during several energy scans.

$t = 15$ hours, the regulator is turned on and the closed-loop level increases in 13 hours to 70%, and then stabilizes. This is a benefit of pressuring the closed loop with dry nitrogen. The gas liquefies and increases the closed-loop level, maintaining it over time. Figure 4b shows the beam positions. The monochromator energy was set at 10.5 keV, and the white beam slits upstream of the monochromator were set to 0.5 mm (H) x 0.25 mm (V). The EPICS EPID loop was on during the whole time series. The vertical fluctuations are $0.69 \mu\text{m}$ rms before the regulator is turned on and are reduced to $0.47 \mu\text{m}$ rms after $t = 15$ hrs. Using feedback and pressure stabilization delivers the best beam stability. Note that the feedback only controls the vertical beam position. During the duration of the time series, the APS had difficulty with some of its sextupole magnets, resulting in larger than usual horizontal beam motion. During fixed-energy operation of the beamline, the day-to-day fluctuations of the horizontal beam position are typically on the order of ten microns. As seen in Fig. 3b, the vertical beam position is kept constant during an energy scan of the monochromator over 800 eV, but some significant residual horizontal beam motion (about $600 \mu\text{m}$) is present.

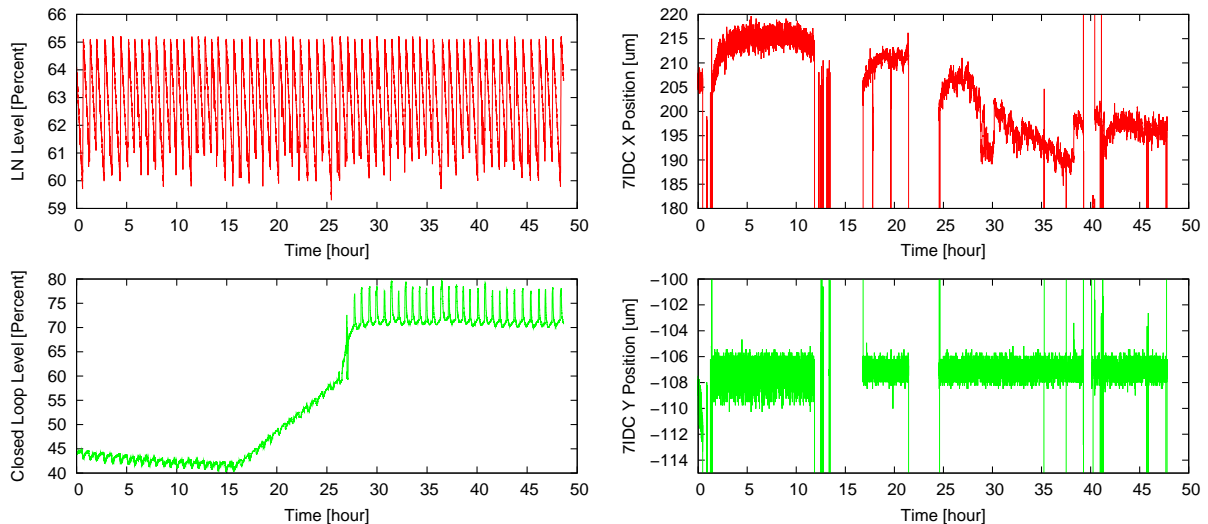


FIGURE 4. A) (left) Outer Dewar level (top) and closed-loop level (bottom) versus time with the new regulated pressure system on. B) (right) Horizontal (X) and vertical (Y) X-ray beam position versus time during the same time series. The regulator circuit is turned on shortly after $t = 15$ hours.

DISCUSSION

With an inexpensive regulator, we have improved the vertical beam position stability of our monochromator to about $0.5 \mu\text{m}$ rms, corresponding to a 25 nrad rms angular stability of the monochromator. The EPICS EPID feedback and pressure regulation provide the best performance. We have found the feedback essential for reproducibly scanning the monochromator energy. The beam stability could be improved further by adding feedback on the horizontal position using a high-resolution actuator to the χ angle of the second crystal. The existing EPICS 0-10V D/A card controlling the second crystal-tilt angle has only 12 bit resolution. Replacing it with a 16 bit card may improve the beam stability further.

ACKNOWLEDGMENTS

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